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CORRELATION PERIODOGRAM INVESTIGATION OF ENGLISH RAINFALL

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[University of Kansas, Lawrence, Kans., December 1933]

English rainfall was chosen for examination because, (*a*) the records are much longer than those of the United States, (*b*) preliminary studies had indicated the possibility of definite positive results by cycle analysis.

In 1929 the writer was sent to England as fellow of the John Simon Guggenheim Memorial Foundation to gather and to analyze rainfall records of that country. Through the courtesy and cooperation of officials of the British Meteorological Service he gathered from the manuscript records of the Rainfall Office a continuous record of the 203 years 1727–1929. In choosing records, the length of record and all notes regarding the manner in which it was kept were considered. Dr. Brooks and Dr. Glasspoole from their familiarity with the subject gave him very much valuable information that improved the results greatly. A desk in the office was given to the writer during the weeks spent in copying and each one with whom he came in contact seemed to strive to make him feel welcome.

The detailed records of the individual stations would be too long to publish here. Table 1 exhibits the stations used and the years for which monthly totals were available. Edinburgh in southeastern Scotland was included with the English stations because of its extremely long record.

In the case of each station the mean value of the record was secured for each month and from these means a table of percentages of normal was formed. Such a procedure weights stations equally for the years used. From these percentages a combined table was made of quarter yearly values, table 2. These are given graphically as figure 1. In it, the first quarter of a given year begins with December of the preceding year. Such quarters match better with the astronomical, meteorological and agricultural quarters than do those of the calendar.

Any long period variations of length much more than 20 or 30 years will be partly damped for the record of the eighteenth century because of the necessary inclusion of records as short as 13 years. No such damping exists for the nineteenth and twentieth centuries. It is important to stress this because of negative evidence regarding long swings such as the Brückner cycle.

Wherever notes showed a significant change in the exposure of the gage, means were taken for the separate exposures. In this connection it is interesting to note that at Exeter the same gage apparently has been used on the top of a wall throughout the whole record. Such an exposure is not the standard one but a uniformity is secured that is invaluable in this type of work. It is hoped that if a change ever is necessary several years of overlapping records of new and of old exposures will be made. Although the record was not used here, it seems well to call attention to the work of Dr. Knox-Shaw at Radcliffe Observatory in the hope that his procedure may be copied by others. The observatory rainfall record was first taken in a roof gage but for many years since then in a more standard exposure. A few years ago the old roof gage was put back into operation in order that the overlapping years may be used to give a homogeneous record. At other stations it probably would be possible to duplicate such work and to improve the records very much.

Before computing the periodogram the writer made an investigation of the permanence of the annual cycle in England and found it subject to large systematic variations. (*1a*) These variations in the type of the annual rainfall are much too large to be accidental and raised the question whether it could be possible for cycles to exist continuously throughout the record. Any cycle existing might plausibly depend upon whatever causes determined the type of the annual rainfall and might cease to exist when the type changed. Many negative results of this paper contribute to this viewpoint and indicate the necessity of further extended study.

The correlation periodogram method need only be outlined very briefly.

Given data x_1, x_2 ---- x_n with x_i representing any datum. Assume the time intervals between x_i and x_{i+1} to be equal. Each datum x_i is matched with the datum l intervals later. l is designated the lag.

$$\text{Compute } r_l \equiv \frac{\Sigma x_i x_{i+l}}{n\sigma_x^2}$$

$$\sigma r_l \equiv \frac{1}{\sqrt{n-l-1}}$$

Values of l are plotted as abscissae and of r_l or of $\frac{r_l}{\sigma r_l}$ as ordinates. The height of the ordinate gives a measure of the probability of a periodicity or cycle of length l.

The periodogram was computed for all values of l from 1 to 352, table 3. This is shown by figure 2.

If long cycles, say 10 years or longer, existed in the data with large amplitude, or if there existed a secular trend to the data, the periodogram should show at first, consistently, large positive ordinates, gradually becoming negative and perhaps again positive. The majority of the first ordinates are positive, but in no case are they large. The writer is forced to the conclusion that the Brückner cycle does not exist in these data. There are successions of dry years and of wet years but the time variation of the swings is too great to give them the term cycle.

In the correlation periodogram a peak is repeated at l, $2l$, $3l$, etc. if a periodicity of length l exists in the data. Therefore if several periodicities exist, there must be unusually high peaks wherever we have approximate least common multiples. Conversely, interference may suppress certain peaks. The following are the values from the periodogram for which $\frac{r_l}{\sigma r_l}$ is greater than plus two.

Lag	Ratio	Lag	Ratio
27	+2.07	147	+2.57
37	+2.15	194	+2.06
75	+2.07	282	+2.80
124	+2.10	338	+2.37

Larger negative ratios are found. Such also could have physical significance.

A study of the larger ratios found shows that there are but few more found than one would expect through accident.

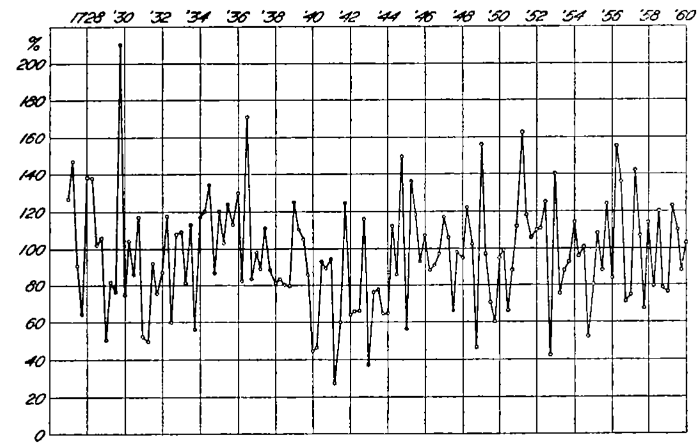

FIGURE 1a.

The increase is scarcely significant. Further evidence will be developed later with respect to the 37–75 peaks, but otherwise the result from this viewpoint must be considered as negative.

There are several possible causes of such negative results:

(a) The data may contain no cycles.

(b) There may be short cycles which vary in length sufficiently that they will show no peak at a lag of ml if m is a fairly large integer. For example, if there were, say, a half dozen cycles of length between 1 and 3 years and if each varied in legnth by as little as 5 percent of its mean during the 203 years of the data, nothing would be found for long lags and but little for short lags.

(c) Short cycles may exist for 25 or 50 years and then become inactive.

(d) Short cycles may exist which are subject to abrupt discontinuities of phase such as Professor Turner suggested for sunspots.

The third of these possibilities must be studied further. For perhaps insufficient reasons, the writer does not favor the fourth. The first two hypotheses may be studied together.

If (b) should be true, it follows that, if we divide the data to form two independent periodograms, there must, for small lags, be a low positive correlation between them. For great enough lags this correlation must become negative and for still greater lags, haphazard. These correlations can never be large because the majority of the peaks of a periodogram will usually be accidental. The lag for which these correlations become negative is a function of the length of the cycles involved and of their percentage change in length.

The first 192 products of each lag of the periodogram were added separately from the remaining products

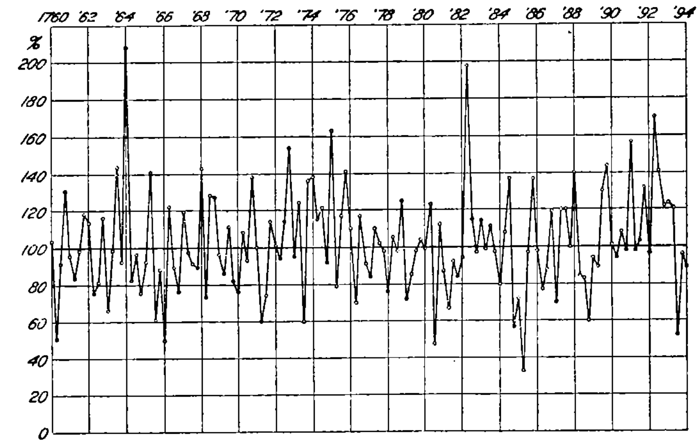

FIGURE 1b.

to give two periodograms, table 3, which are independent, despite some duplication of data. Up to a lag of approximately 150 the correlation between the periodograms is rather consistently positive with the sum of positive products about twice as large as of negative. From here, till near the end, the reverse is true. This evidence strongly favors the existence of a plurality of short cycles. The rather large lag at which the reversal of the correlation takes place indi-

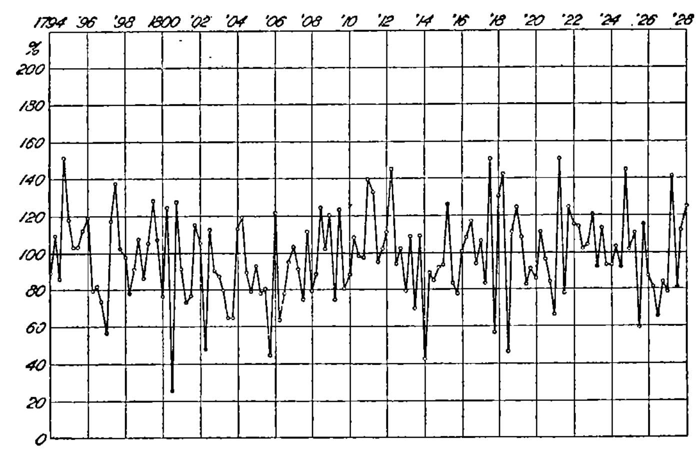

FIGURE 1c.

cates that the percentage variation in length is quite small.

In 1922 the writer published (1b) an investigation of rainfall data from many parts of the world which seemed to show quite definitely that there does exist, in numerous places, a rainfall cycle whose phase varies with sunspot phase instead of time and with a length of one ninth the sunspot cycle. The adjustment to sunspot phase by his tables can be carried back only to the year 1860. Monthly values from these data were examined by means of the tables of that paper to study the possibility of existence of this short cycle in them. The values for this cycle for the halves of the data 1860–1929 are superposed in figure 3. The correlation between them is $r = +0.51$. This value, in con-

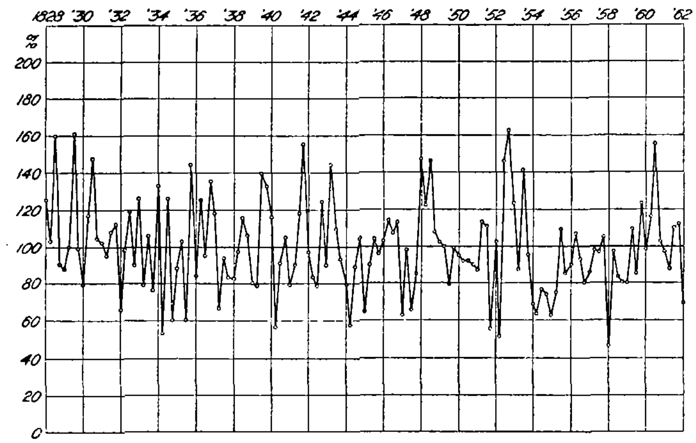

Figure 1d.

junction with the evidence of the independent periodograms and that from the 1922 paper, may be regarded as confirming the existence here of this short variable

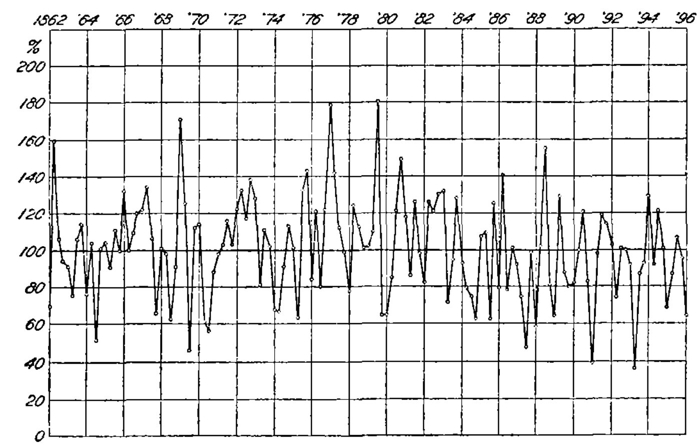

Figure 1e.

cycle. The shape of the curve shows that it itself is merely a complex of its harmonies.

When the independent periodograms were examined, it was found that the peak at lag 27 was not consistent

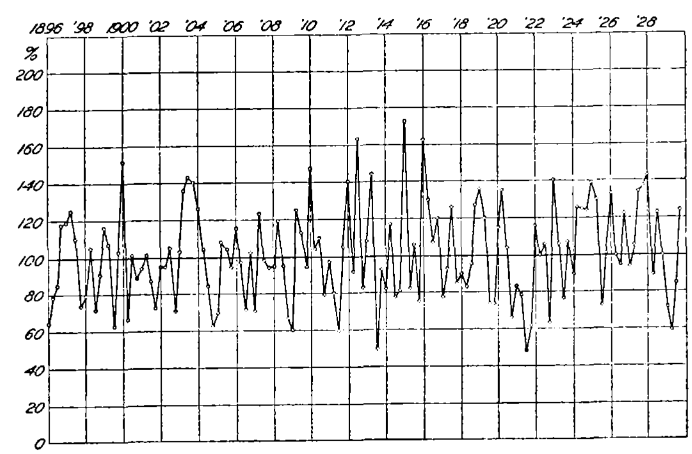

Figure 1f.

through the data, and, therefore, is presumably accidental. However, that at 37 and its double at 75 are consistent and warrant further study. For this purpose the 203 years of data were divided into six sections and each tabulated separately for a 37½ quarter cycle. Each of these six curves was then matched to give the best fit

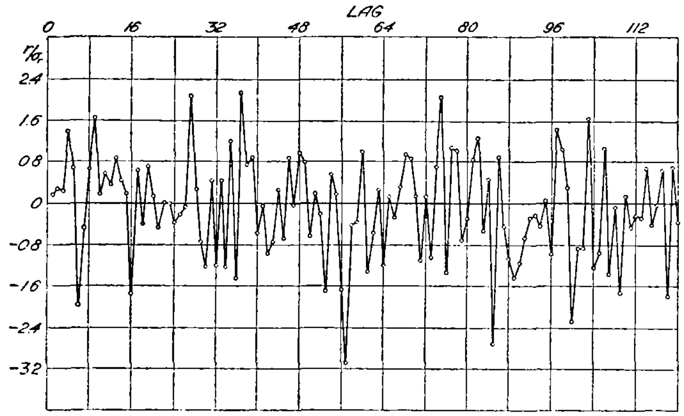

Figure 2a.

with the mean of all. The number of quarters by which it was necessary to shift a curve to match it best with the mean curve, gives a measure of its variation in length

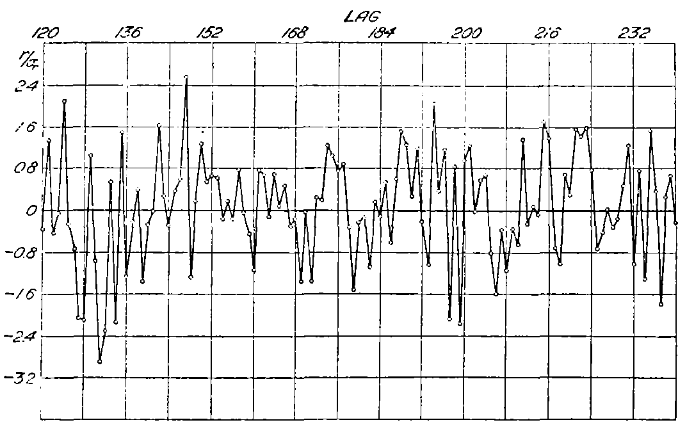

Figure 2b.

between these sections of the data if the hypothesis of its real existence be true. These variations expressed as percentages of the mean length are shown in figure 4. On them are superposed the percentage variations for the sun-spot numbers for the same intervals. The resemblance is very strong and, therefore, having admitted the existence

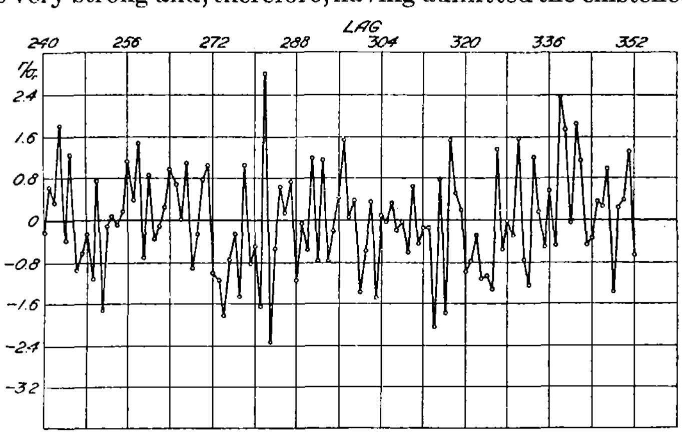

Figure 2c.

of one other cycle which varies in a similar manner, this one must be regarded as probably real. It probably is not entirely independent of the shorter one.

SUMMARY OF RESULTS

(*a*) Long cycles do not exist in these data.
(*b*) Strictly periodic terms do not exist.
(*c*) At least one and probably more cycles do exist which vary their phase in step with the sun-spot numbers.
(*d*) Nothing has been developed to give long-range predictions of any commercial value.
(*e*) Several facts indicate the value of a further extended study of the data.

The writer wishes to acknowledge grants from the Research Committee of the Graduate School of the University of Kansas by which the majority of the computing was carried out partly under the direction of Director L. J. Comrie of the British Nautical Almanac Office and partly by Miss Sylvia Burd of the University of Kansas. He wishes also to thank the John Simon Guggenheim Memorial Foundation for the entire freedom they granted him in carrying out the study and for their patience with him through several years of delayed publication.

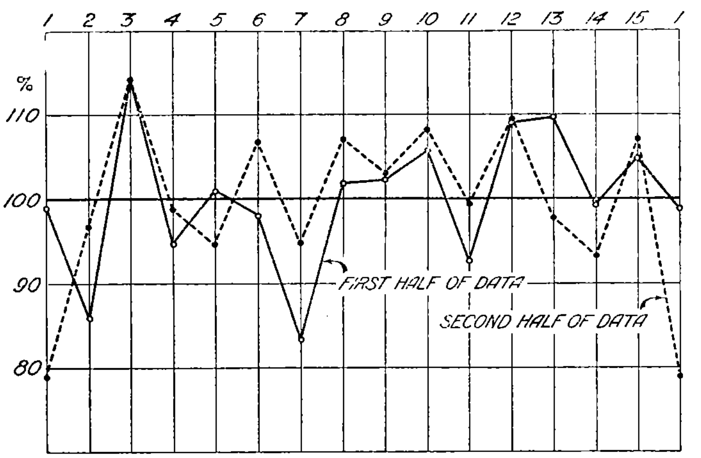

FIGURE 3.

LITERATURE CITED

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(*a*) Peculiarity in the variation of distribution of the annual rainfall. Met. Mag. vol. 64, no. 766, November 1929, pp. 234–5.
(*b*) A rainfall period equal to one ninth the sun-spot period. Kansas University Science Bulletin, vol. XIII, no. 11, July 1922, pp. 17–99.

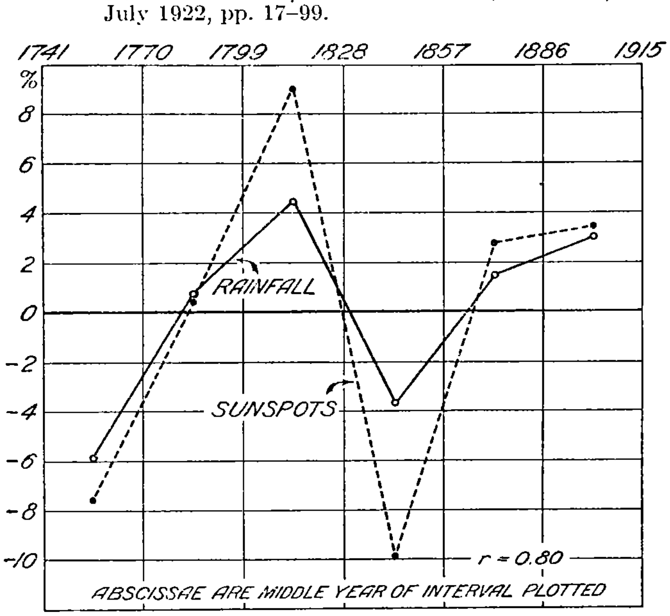

FIGURE 4.

TABLE 1.—*Data used*

Southwick	1727 I –1739 IV
Plymouth	1727 I –1752 IV
Lyndon	1736 III–1798 IV
Norwich	1750 I –1762 IV
Carlisle	1757 I –1783 IV
Peebles	1766 I –1779 IV
Chatsworth	1777 I –1793 III
	1800 I –1813 IV
Liverpool	1775 I –1792 IV
Edinburgh	1770 I –1776 IV
	1780 I –1781 II
	1785 I –1929 IV
Manchester	1794 I –1840 IV
Exeter	1817 I –1929 IV
Greenwich	1815 I –1929 IV
Spalding	1829 I –1929 IV
Stonyhurst	1848 I –1929 IV
Chilgrove	1834 I –1929 IV

When the records showed a sufficient change in exposure new means were formed.

TABLE 2.—*English rainfall data*

[Percentages of normal. First quarter of each year begins with December of preceeding year]

	Quarters					Quarters			
	I	II	III	IV		I	II	III	IV
1727	127	147	91	64	1796	119	79	81	73
1728	138	138	102	106	1797	56	117	137	102
1729	50	81	76	210	1798	97	77	91	107
1730	74	104	86	117	1799	86	105	128	107
1731	52	49	92	75	1800	76	124	25	127
1732	87	118	60	108	1801	91	72	76	115
1733	109	81	113	56	1802	105	47	112	90
1734	117	120	134	87	1803	87	79	64	64
1735	120	103	124	113	1804	113	119	89	78
1736	130	82	170	83	1805	93	77	80	44
1737	98	89	111	88	1806	121	63	77	95
1738	81	83	80	79	1807	103	91	74	111
1739	125	110	105	86	1808	79	88	124	102
1740	44	46	93	89	1809	120	74	123	80
1741	94	27	60	124	1810	88	108	98	97
1742	64	65	66	116	1811	139	132	95	102
1743	37	76	77	64	1812	111	145	94	102
1744	64	112	86	149	1813	79	109	69	109
1745	56	136	118	93	1814	42	89	85	92
1746	107	88	91	97	1815	93	126	83	77
1747	117	106	66	98	1816	101	108	117	94
1748	95	122	102	46	1817	106	83	150	56
1749	156	97	70	60	1818	130	142	46	111
1750	95	99	66	88	1819	124	108	82	91
1751	112	162	118	106	1820	86	111	96	84
1752	110	111	125	42	1821	66	150	77	124
1753	140	75	88	93	1822	115	114	102	104
1754	114	96	101	52	1823	120	92	113	93
1755	80	108	88	124	1824	93	103	92	144
1756	84	155	136	71	1825	102	110	59	115
1757	74	142	107	67	1826	87	81	65	84
1758	114	79	120	78	1827	78	141	81	112
1759	76	123	110	88	1828	125	103	160	90
1760	103	51	91	130	1829	88	100	161	99
1761	95	83	98	118	1830	79	117	147	104
1762	113	75	81	116	1831	102	95	108	112
1763	66	98	144	92	1832	65	98	119	90
1764	208	82	96	75	1833	126	79	106	76
1765	92	141	61	88	1834	133	53	126	60
1766	50	122	89	76	1835	88	103	60	144
1767	119	97	91	89	1836	84	125	95	135
1768	143	73	128	127	1837	118	66	94	83
1769	96	86	111	82	1838	82	97	115	106
1770	76	108	93	138	1839	80	78	139	132
1771	100	60	74	114	1840	116	56	91	105
1772	101	94	114	154	1841	79	90	118	155
1773	95	124	60	136	1842	97	83	78	124
1774	138	115	121	92	1843	90	144	109	93
1775	163	79	117	141	1844	79	57	89	104
1776	110	70	117	91	1845	64	90	104	96
1777	84	110	102	98	1846	103	114	107	113
1778	76	105	98	125	1847	62	98	65	85
1779	72	85	98	104	1848	147	122	146	108
1780	99	123	48	112	1849	102	100	79	99
1781	87	67	92	84	1850	95	92	92	90
1782	94	198	115	97	1851	87	113	111	55
1783	114	99	111	97	1852	102	51	146	162
1784	80	108	137	57	1853	123	87	141	95
1785	72	33	97	137	1854	68	63	76	73
1786	98	77	88	119	1855	62	74	109	85
1787	70	120	120	100	1856	90	107	93	80
1788	140	84	83	60	1857	86	98	97	105
1789	94	89	130	144	1858	46	97	83	80
1790	101	94	108	98	1859	80	109	85	123
1791	157	98	103	132	1860	98	116	155	102
1792	96	170	141	122	1861	97	88	110	112
1793	123	121	53	96	1862	69	159	106	94
1794	89	109	86	151	1863	91	75	106	114
1795	118	103	103	112	1864	76	104	51	101

TABLE 2.—*English rainfall data*—Continued

	Quarters					Quarters			
	I	II	III	IV		I	II	III	IV
1865	104	91	111	100	1898	79	105	71	91
1866	132	100	109	120	1899	116	107	62	103
1867	122	134	106	65	1900	151	66	101	89
1868	101	98	62	91	1901	94	101	87	72
1869	170	125	46	112	1902	95	95	105	70
1870	114	61	56	88	1903	103	136	143	140
1871	98	103	116	103	1904	126	104	84	62
1872	122	132	117	138	1905	69	108	104	94
1873	128	81	111	102	1906	115	97	71	112
1874	67	66	91	113	1907	70	123	98	94
1875	101	63	132	143	1908	95	119	95	66
1876	84	121	80	122	1909	60	125	113	94
1877	178	142	112	99	1910	147	104	110	79
1878	77	124	113	101	1911	97	80	59	105
1879	102	110	180	64	1912	140	92	163	83
1880	64	85	121	149	1913	108	144	49	93
1881	118	86	126	98	1914	82	117	77	81
1882	82	126	121	130	1915	172	82	106	75
1883	132	71	95	128	1916	162	130	107	120
1884	93	79	74	62	1917	77	93	126	85
1885	107	109	62	125	1918	90	83	96	127
1886	79	140	78	101	1919	136	120	73	73
1887	92	74	47	99	1920	115	135	104	66
1888	58	102	155	81	1921	83	78	48	61
1889	64	129	88	80	1922	116	100	106	63
1890	82	100	121	83	1923	140	106	76	107
1891	39	98	119	114	1924	90	126	125	124
1892	103	74	101	100	1925	139	130	72	101
1893	92	36	87	93	1926	133	100	95	122
1894	129	92	121	101	1927	94	106	134	137
1895	69	87	107	96	1928	143	90	123	100
1896	64	78	85	118	1929	71	59	85	124
1897	119	125	110	73					

TABLE 3.—*Correlation periodogram of English rainfall*

Lags	Entire periodogram		$r_l/\sigma r_l$ of independent parts of periodogram		Lags	Entire periodogram		$r_l/\sigma r_l$ of independent parts of periodogram	
	r_l	$r_l/\sigma r_l$	Part A	Part B		r_l	$r_l/\sigma r_l$	Part A	Part B
1	+0.005	+0.15	−1.18	+0.83	53	−0.061	−1.69	−1.61	−1.01
2	+.009	+.25	+.80	−.16	54	+.019	+.53	−.32	+.81
3	+.007	+.21	+.77	−.20	55	+.006	+.17	+.45	−.07
4	+.049	+1.37	+2.43	+.21	56	−.061	−1.68	−1.21	−1.23
5	+.025	+.68	+1.72	−.17	57	−.112	−3.09	−2.96	−1.82
6	−.068	−1.94	−.96	−1.68	58	−.016	−.43	+.52	−.80
7	−.017	−.49	+.65	−.93	59	−.014	−.38	+.22	−.57
8	+.0225	+.64	+.70	+.33	60	+.035	+.97	+1.20	+.40
9	+.058	+1.65	+1.33	+1.14	61	−.048	−1.33	−1.97	−.36
10	+.006	+.17	+.05	+.16	62	−.022	−.59	+.93	−1.24
11	+.021	+.57	−.43	+.92	63	+.009	+.24	−.01	+.29
12	+.012	+.35	+.20	+.27	64	−.044	−1.20	−.88	−.87
13	+.030	+.86	+.34	+.80	65	+.004	+.11	−.44	+.39
14	+.015	+.42	+.03	+.46	66	−.010	−.28	+.39	−.55
15	+.006	+.18	−1.14	+.86	67	+.011	+.31	+.76	−.10
16	−.062	−1.73	−1.49	−1.15	68	+.034	+.93	+.77	+.61
17	+.022	+.61	−.52	+1.01	69	+.031	+.84	+.92	+.42
18	−.014	−.41	−.12	−.46	70	+.004	+.12	+.16	+.05
19	+.025	+.70	+.25	+.66	71	−.041	−1.11	−1.13	−.60
20	+.004	+.12	−.82	+.61	72	+.004	+.12	+.64	−.25
21	−.017	−.48	+1.91	−1.64	73	−.039	−1.06	+.96	−1.80
22	.000	+.01	+.47	−.26	74	+.025	+.69	+1.16	+.10
23	−.000	.00	−.88	+.50	75	+.076	+2.07	+2.50	+.88
24	−.014	−.39	−.64	−.08	76	−.049	−1.33	−.69	−1.13
25	−.008	−.22	+1.76	−1.26	77	+.039	+1.05	+1.74	+.18
26	−.003	−.08	−1.45	+.74	78	+.037	+1.00	+.09	+1.10
27	+.074	+2.07	+.65	+2.01	79	−.026	−.70	−.32	−.63
28	+.010	+.28	−.15	+.40	80	−.011	−.30	−1.07	+.30
29	−.027	−.75	−.31	−.68	81	+.030	+.82	+.28	+.78
30	−.044	−1.23	−.15	−1.32	82	+.046	+1.24	−.42	+1.68
31	+.015	+.42	+.79	+.03	83	−.020	−.54	−.96	−.05
32	−.043	−1.20	−1.35	−.59	84	+.017	+.45	+.47	+.24
33	+.015	+.43	+1.58	−.43	85	−.110	−2.71	−2.31	−1.74
34	−.044	−1.23	−.80	−.95	86	+.032	+.87	+1.61	+.04
35	+.043	+1.19	+1.00	+.79	87	−.017	−.45	+.86	−1.04
36	−.051	−1.44	−.71	−1.24	88	−.041	−1.09	−.94	−.70
37	+.077	+2.15	+1.25	+1.73	89	−.053	−1.44	+.34	−1.88
38	+.026	+.73	+1.03	+.24	90	−.043	−1.16	−.64	−.96
39	+.031	+.87	+.96	+.45	91	−.025	−.68	+.43	−1.06
40	−.021	−.59	−.58	−.34	92	−.011	−.30	+.09	−.40
41	−.002	−.06	+.56	−.39	93	−.009	−.25	−.37	−.07
42	−.036	−.99	+.42	−1.38	94	−.017	−.45	+.52	−.84
43	−.027	−.75	+.08	−.90	95	+.002	+.05	+.58	−.29
44	+.009	+.25	+.96	−.26	96	−.037	−1.00	−.75	−.71
45	−.025	−.70	−.03	−.79	97	+.052	+1.40	+.71	+1.20
46	+.029	+.81	+.70	+.52	98	+.038	+1.01	+.03	+1.17
47	−.001	−.02	+.83	−.51	99	+.001	+.03	−.10	+.10
48	+.035	+.96	+.77	+.66	100	−.085	−2.28	−1.15	−1.95
49	+.028	+.79	+.14	+.82	101	−.033	−.38	−.95	−.45
50	−.023	−.65	+.79	−1.20	102	−.036	−.89	−2.27	+.27
51	+.007	+.19	−.22	+.35	103	+.061	+1.63	+1.18	+1.18
52	−.008	−.21	−1.07	+.39	104	−.047	−1.25	+.54	−1.80

TABLE 3.—*Correlation periodogram of English rainfall*—Continued

Lags	Entire periodogram		$r_l/\sigma r_l$ of independent parts of periodogram		Lags	Entire periodogram		$r_l/\sigma r_l$ of independent parts of periodogram	
	r_l	$r_l/\sigma r_l$	Part A	Part B		r_l	$r_l/\sigma r_l$	Part A	Part B
105	−0.036	−0.97	−0.94	+0.56	204	+0.026	+0.65	−1.73	+1.97
106	+.039	+1.03	+.76	+.75	205	−.033	−.80	−1.14	−.18
107	−.052	−1.38	−1.03	−.98	206	−.065	−1.60	−.47	−1.60
108	−.004	−.10	+1.27	−.91	207	−.016	−.39	−.82	−.10
109	−.065	−1.71	−1.07	−1.68	208	−.047	−1.15	−1.22	−.54
110	+.004	+.11	+.41	−.12	209	−.015	−.37	−2.03	+.94
111	−.019	−.49	+.05	−.60	210	−.026	−.65	+.40	−1.05
112	−.009	−.25	−.07	−.25	211	+.055	+1.35	+.21	+1.46
113	−.011	−.30	+.02	−.79	212	−.010	−.25	+.68	−.77
114	+.025	+.67	+.89	+.33	213	+.003	+.08	−1.01	+.79
115	−.016	−.42	−.06	−.45	214	−.004	−.09	+.14	−.20
116	−.001	−.03	−.13	+.05	215	+.070	+1.70	−.06	+2.09
117	+.023	+.60	+.92	+.13	216	+.057	+1.38	+1.77	+.44
118	−.067	−1.78	−2.10	−.77	217	−.030	−.72	−.43	−.58
119	+.026	+.69	−.41	+1.06	218	−.042	−1.03	−1.66	−.10
120	−.014	−.37	−.28	−.26	219	+.028	+.68	+1.19	.00
121	+.050	+1.31	−.39	+1.79	220	+.012	+.30	+1.04	−.37
122	−.016	−.43	−.59	−.14	221	+.064	+1.56	+.89	+1.27
123	−.005	−.07	−1.41	+.81	222	+.058	+1.41	+.56	+1.31
124	+.080	+2.10	+1.21	+1.71	223	+.065	+1.59	+.83	+1.34
125	−.010	−.27	+1.29	−1.13	224	+.032	+.77	+1.40	−.04
126	−.028	−.74	−1.27	−.10	225	−.031	−.76	−.08	−.87
127	−.077	−2.02	−.97	−1.75	226	−.018	−.43	+.92	−1.17
128	−.079	−2.08	−1.48	−1.51	227	.000	+.01	−.28	+.21
129	+.039	+1.02	+.52	+.88	228	−.013	−.32	+.23	−.56
130	−.037	−.98	−2.90	+.69	229	−.008	−.18	+.38	−.49
131	−.111	−2.90	−3.48	−1.00	230	+.019	+.46	−.14	+.66
132	−.009	−.23	−1.74	+.83	231	+.051	+1.22	+1.26	+.60
133	+.020	+.51	+1.04	−.06	232	−.043	−1.03	−1.27	−.36
134	−.046	−1.21	−.97	−.81	233	+.030	+.72	+.86	+.37
135	+.057	+1.50	+.18	+1.65	234	−.054	−1.31	−.45	−1.29
136	−.049	−1.27	−.41	−1.24	235	+.063	+1.51	+.72	+1.32
137	−.009	−.23	+.05	−.30	236	+.015	+.37	−.47	+.78
138	+.015	+.38	+.15	+.36	237	−.074	−1.78	+.02	−2.18
139	−.052	−1.36	−1.16	−.87	238	+.011	+.26	+.53	−.06
140	−.012	−.31	−1.18	+.40	239	+.028	+.67	+1.56	−.30
141	−.001	−.02	+.11	−.10	240	−.009	−.23	+1.42	−1.30
142	+.063	+1.63	+3.42	−.26	241	+.026	+.62	+.85	+.16
143	+.010	+.26	−.45	+.81	242	+.013	+.31	−1.90	+1.75
144	−.012	−.30	+.34	−.55	243	+.076	+1.82	+2.52	+.40
145	+.014	+.35	−.70	+.86	244	−.017	−.40	−.67	−.01
146	+.022	+.58	+.69	+.24	245	+.051	+1.22	+.92	+.83
147	+.100	+2.57	+2.96	+1.15	246	−.041	−.97	−1.53	−.08
148	−.049	−1.27	−.184	−.31	247	−.028	−.63	+.64	−1.27
149	+.006	+.16	−.83	+.72	248	−.012	−.28	+.10	−.41
150	+.049	+1.26	+.40	+1.25	249	−.047	−1.12	+.41	−1.67
151	+.020	+.52	−.44	+.90	250	+.031	+.73	+1.27	+.05
152	+.025	+.64	+1.41	−.31	251	−.072	−1.70	−.17	−1.95
153	+.024	+.61	+1.03	+.05	252	−.006	−.13	+.84	−.77
154	−.007	−.17	+.75	−.69	253	.000	+.07	+1.43	−1.03
155	+.006	+.16	+.40	−.08	254	−.004	−.10	−.62	+.33
156	−.007	−.18	+.96	−.84	255	+.006	+.15	+1.09	−.62
157	+.030	+.77	+.24	+.76	256	+.047	+1.10	+.17	+1.23
158	−.002	−.05	−1.37	+.83	257	+.016	+.38	+2.06	−1.04
159	−.018	−.46	+.20	−.68	258	+.062	+1.45	+1.17	+.93
160	−.014	−1.13	−.13	−1.25	259	−.030	−.71	−2.00	+.60
161	+.030	+.77	+.33	+.69	260	+.036	+.84	+2.52	−.82
162	+.027	+.68	+.01	+.81	261	−.016	−.38	+1.74	−1.77
163	−.005	−.13	+.21	−.29	262	−.005	−.12	+.79	−.75
164	+.027	+.69	+.37	+.40	263	+.009	+.22	+.43	−.05
165	+.003	+.06	−.76	+.66	264	+.041	+.95	+1.12	+.35
166	+.018	+.45	+.14	+.44	265	+.029	+.69	+.26	+.67
167	−.012	−.31	−1.63	+.69	266	+.001	+.01	−.52	+.40
168	−.008	−.19	−.28	−.04	267	+.046	+1.08	+1.75	+.04
169	−.055	−1.38	−.94	−1.03	268	−.040	−.93	−1.35	−.15
170	−.002	−.04	−.25	+.11	269	−.011	−.27	−.35	−.07
171	−.054	−1.37	−.14	−1.55	270	+.033	+.77	+.19	+.82
172	+.009	+.22	−.55	+.63	271	+.043	+1.01	+2.09	−.31
173	+.008	+.19	+.92	−.38	272	−.047	−1.09	−.45	−1.02
174	+.048	+1.21	+.58	+1.06	273	−.050	−1.50	−2.20	−.21
175	+.040	+1.02	+.57	+.83	274	−.078	−1.81	−1.39	−1.21
176	+.030	+.74	−1.31	+1.76	275	−.032	−.75	−.10	−.87
177	+.034	+.87	+.86	+.46	276	−.012	−.27	+1.50	−1.47
178	−.013	−.34	−.39	−.15	277	−.068	−1.56	−1.46	−.87
179	−.061	−1.53	−.32	−1.61	278	+.044	+1.01	+.35	+1.01
180	−.009	−.24	−.13	−.20	279	−.035	−.81	−1.68	+.25
181	−.006	−.16	+.61	−.60	280	−.022	−.50	+1.40	−1.69
182	−.014	−1.10	−1.01	−.65	281	−.071	−1.64	−3.23	+.42
183	+.006	+.15	+1.45	−.78	282	+.126	+2.80	+1.33	+2.60
184	−.005	−.12	−1.44	+.79	283	−.101	−2.32	−2.43	−1.04
185	+.021	+.53	+.88	+.05	284	+.024	+.55	+1.66	−.59
186	−.025	−.62	−.64	−.32	285	−.008	−.18	−.03	−.21
187	+.024	+.60	+1.18	−.08	286	−.030	−.68	−.90	−.17
188	+.050	+1.51	+.66	+1.37	287	−.004	−.08	+.34	−.36
189	+.050	+1.25	+.11	+1.42	288	−.050	−1.14	+.73	−1.98
190	+.010	+.24	+.66	−.15	289	−.003	−.08	+1.92	−1.57
191	+.018	+1.19	+.67	+.98	290	−.025	−.57	−1.62	+.53
192	−.009	−.23	+1.29	−1.15	291	+.052	+1.18	+1.95	−.03
193	−.012	−1.05	−.99	−.60	292	−.034	−.77	+.40	−1.27
194	+.083	+2.06	+.99	+1.80	293	+.041	+.93	+.29	+.95
195	+.015	+.36	−.69	−.90	294	−.034	−.77	+.11	−1.07
196	+.047	+1.16	−.54	+1.69	295	−.009	−.21	−.20	−.10
197	−.084	−2.07	−2.23	−.98	296	+.018	+.41	−.46	−.87
198	+.036	+.90	+.45	+.77	297	+.067	+1.52	+.61	+1.43
199	−.087	−2.15	−2.86	−.65	298	+.002	+.05	+1.59	−1.17
200	+.039	+.95	−1.08	+1.89	299	+.017	+.38	+.76	−.12
201	+.050	+1.22	+.69	+1.00	300	−.060	−1.37	−1.96	−.19
202	−.001	−.02	+.45	−.33	301	−.026	−.59	−.43	−.41
203	+.023	+.57	−2.18	+2.19	302	+.014	+.33	+.68	−.12

TABLE 3.—*Correlation periodogram of English rainfall*—Continued

Lags	Entire periodogram		$r_l/\sigma r_l$ of independent parts of periodogram		Lags	Entire periodogram		$r_l/\sigma r_l$ of independent parts of periodogram	
	r_l	$r_l/\sigma r_l$	Part A	Part B		r_l	$r_l/\sigma r_l$	Part A	Part B
303	−0.066	−1.48	+0.39	−2.18	316	−0.080	−1.78	−1.58	−0.98
304	+.004	+.08	+.77	−.56	317	+.069	+1.53	+.46	+1.58
305	−.002	−.03	−.28	+.18	318	+.022	+.50	+.42	+.30
306	+.014	+.31	+.67	−.14	319	+.009	+.19	−1.26	+1.26
307	−.009	−.20	−.69	+.29	320	−.045	−1.00	−.23	−1.11
308	−.001	−.03	−.19	+.12	321	−.036	−.80	−.63	−.50
309	−.027	−.60	+.66	−1.28	322	−.013	−.30	+.80	−1.02
310	+.028	+.63	−.95	+1.56	323	−.051	−1.12	−1.82	+.04
311	−.020	−.45	+.28	−.80	324	−.049	−1.08	−.92	−.63
312	−.008	−.17	−.81	+.43	325	−.059	−1.31	−1.31	−.60
313	−.007	−.15	+.34	−.47	326	+.061	+1.34	+.51	+1.30
314	−.090	−2.01	−1.72	−1.18	327	−.025	−.55	−1.54	+.55
315	+.035	+.78	+1.21	+.02	328	−.001	−.15	−.70	+.55

TABLE 3.—*Correlation periodogram of English rainfall*—Continued

Lags	Entire periodogram		$r_l/\sigma r_l$ of independent parts of periodogram		Lags	Entire periodogram		$r_l/\sigma r_l$ of independent parts of periodogram	
	r_l	$r_l/\sigma r_l$	Part A	Part B		r_l	$r_l/\sigma r_l$	Part A	Part A
329	−0.014	−0.30	+0.36	−0.67	341	+0.086	+1.86	+0.98	+1.52
330	+.071	+1.55	+1.38	+.87	342	+.042	+.91	+.60	+.68
331	−.035	−.76	+.07	−1.03	343	−.022	−.47	−.60	−.12
332	−.057	−1.25	−.90	−.88	344	−.016	−.34	−1.21	+.58
333	+.054	+1.19	+.73	+.93	345	+.016	+.34	−.21	+.62
334	+.007	+.15	−1.24	+1.21	346	+.012	+.26	−1.23	+1.38
335	−.023	−.50	+.32	−.91	347	+.045	+.98	+.77	+.74
336	+.025	+.55	+1.29	−.37	348	−.063	−1.36	−2.07	−.02
337	−.022	−.48	−1.05	+.25	349	+.011	+.23	+.20	+.13
338	+.109	+2.37	+1.41	+1.90	350	+.018	+.39	+.31	+.24
339	+.080	+1.74	+.48	+1.88	351	+.061	+1.30	+.39	+1.37
340	−.002	−.04	−.98	+.77	352	−.032	−.69	−1.86	+.70

SIGNIFICANT CHANGES IN THE RAINFALL AT SOME LOCALITIES

By DEAN A. PACK

INTRODUCTION

These data are presented to support the generally prevalent, though many times questioned, belief in weather recurrences and weather cycles. No attempt has been made to establish any direct or indirect relation between precipitation and sun-spot cycles or any other kind of periodic variation. However, an effort has been made to show that precipitation cycles do exist, and that the precipitation for many different localities show significant changes from period to period.

SUMMARY

These points have been supported by the calculation of cycles for several precipitation records, and by showing that the differences in the amount of rainfall during the maximum and during the minimum periods for these records could not be due to chance alone.

A cycle or trend for each precipitation record was calculated and the curve plotted, so that the periods of high or low average rainfall could be located. This was done for the annual precipitation records of 41 stations in the United States and 12 stations in other parts of the world. The crests and troughs of these curves indicated periods of maximum or high average and periods of minimum or low average rainfall for each station, respectively. The annual precipitation during the periods of maximum rain fall were compared statistically with the annual precipitation during the periods of minimum rainfall for each station. The results show that the precipitation for each station passes through a particular cycle during which time it varies by significant amounts. As a result there are significant maximum and minimum periods.

The annual precipitation during successive maxima periods and minima periods were also statistically compared. No significant difference of average annual precipitation was found between successive maxima periods or between successive minima periods for any particular station. While this indicates that successive cycles may have about the same amplitude, no definite conclusion is possible because our weather records are too short.

HISTORICAL

Sir Richard Gregory's (**6**) address before the Royal Meteorological Society will be found of interest as a review of the present opinion on weather cycles and of the more recent literature. In 1915 Goodnough (**3**) pointed out that the rainfall for various localities in New England changed from time to time. In 1930 he (**4**) presented the following table 1 which is self-explanatory and which is reprinted here by permission of the New England Water Works Association.

TABLE 1.—*Average annual rainfall by periods (inches)*

Period	New Bedford, Mass.	Boston, Mass.	Waltham, Mass.	Lowell, Mass.
1826–49, 24 years	47.21	42.00	41.13	39.45
1850–76, 27 years	46.73	53.18	43.00	45.73
1877–1903, 27 years	47.79	45.52	44.40	45.95
1904–29, 26 years	44.23	40.32	40.24	41.43
1826–1929, 104 years	46.49	45.40	42.24	43.26

Marvin (**7**) in an article entitled "Concerning Normals, Secular Trends and Climatic Changes" discussed the precipitation changes for Boston vicinity from 1758 on. Powell (**8**) presented a method for finding long period cycles and showed that a cosine curve fits the Boston precipitation data much closer than straight line trends.

SOURCES OF MATERIAL

The data used for these calculations were taken from the records of the United States Weather Bureau, the New England Water Works Association, the Smithsonian Institution (**1**), and the Meteorological Service of Canada.

INVESTIGATION

The Goutereau (**5**) Ratio was applied to several annual precipitation records, with a result that the data indicated the presence of a cycle.

In order to select periods from the annual precipitation records that had a high or low average annual precipitation, cycles were calculated and curves drawn for the precipitation record of each station. These cycles were calculated by the least squares method or by moving averages. The least square method was used only on parts of long records that could be represented by more simple curves. From these curves, it was an easy matter to select from the records periods having either a high or a low average annual precipitation.